DTIC FILE COPY

AFGL-TR-88-0274

(2)

AD-A200 761

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

Paper Reprinted from
Conference Proceedings No.419

SCATTERING AND PROPAGATION IN RANDOM MEDIA

NORTH ATLANTIC TREATY ORGANIZATION

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS: None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFGL-TR-88-0274	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Air Force Geophysics Laboratory; 6b. OFFICE SYMBOL (If applicable): LIS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code): Hanscom AFB, Massachusetts 01731-5000	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62101F	4643	09	03

11. TITLE (Include Security Classification): Ionospheric Scintillations... (see reverse)

12. PERSONAL AUTHOR(S): Santimay Basu, Sunanda Basu*, Eileen MacKenzie*, and Dan Weimer

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Reprint	FROM ______ TO ______	1988 October 4	12

16. SUPPLEMENTARY NOTATION *Emmanuel College, Boston MA 02115.
Paper reprinted from AGARD Conference Proceedings No. 419, May, 1987. This research was supported in part by Emmanuel College Contract F19628-86-K-0038 & the Defense Nuclear Agency.

17. COSATI CODES		
FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Amplitude and phase scintillations; total electron content; in-situ density; auroral oval; sunspot cycle variation; irregularity anisotropy. Reprints (jhd)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The orbiting HiLat satellite launched by the Defense Nuclear Agency in 1983 offered a unique opportunity for studying the ionospheric scintillation parameters in relation to the in-situ measurements of ionization density, drift velocity, field-aligned current, and particle precipitation during the sunspot minimum period. This paper discusses the ~~results of such a morphological study~~, performed by the Air Force Geophysics Laboratory based on ~~their~~ observations at the auroral oval station of Tromso, Norway. The dynamics of the spatial and temporal extent of this region are illustrated in the invariant latitude/magnetic local time grid. The geometrical enhancement of scintillations observed during the alignment of the propagation path with the local magnetic L-shell is shown to be the most consistent and conspicuous feature of scintillations in the nighttime auroral oval. The steepening of phase spectral slope in this region is indicative of the presence of L-shell aligned sheet-like irregularities at long scale lengths. The seasonal

(continued on reverse)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Santimay Basu	22b. TELEPHONE NUMBER (Include Area Code): (617) 377-3141; 22c. OFFICE SYMBOL: AFGL/LIS

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

11. Title (continued)

Ionospheric Scintillations and In-Situ Measurements at an Auroral Location in the European Sector

19. Abstract (continued)

variation of total electron content (TEC) determined from the differential Doppler measurements of HiLat transmissions is discussed in relation to the in-situ density measurements at 830 km. The results are also utilized to illustrate the dependence of ionospheric structure parameters on short-term variability of solar activity during the sunspot minimum period. Special effort is made to illustrate that the joint study of scintillation/TEC and in-situ parameters provides an insight into the nature of magnetospheric coupling with the high latitude ionosphere.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

IONOSPHERIC SCINTILLATIONS AND IN-SITU MEASUREMENTS AT AN AURORAL LOCATION IN THE EUROPEAN SECTOR

Santimay Basu
Air Force Geophysics Laboratory
Hanscom AFB MA 01731

Sunanda Basu and Eileen MacKenzie
Emmanuel College
Boston MA 02115

Dan Weimer
Regis College
Weston MA 02193

SUMMARY

The orbiting HiLat satellite launched by the Defense Nuclear Agency in 1983 offered a unique opportunity for studying the ionospheric scintillation parameters in relation to the in-situ measurements of ionization density, drift velocity, field-aligned current, and particle precipitation during the sunspot minimum period. This paper discusses the results of such a morphological study performed by the Air Force Geophysics Laboratory based on their observations at the auroral oval station of Tromso, Norway. The dynamics of the spatial and temporal extent of this region are illustrated in the invariant latitude/magnetic local time grid. The geometrical enhancement of scintillations observed during the alignment of the propagation path with the local magnetic L-shell is shown to be the most consistent and conspicuous feature of scintillations in the nighttime auroral oval. The steepening of phase spectral slope in this region is indicative of the presence of L-shell aligned sheet-like irregularities at long scale lengths. The seasonal variation of total electron content (TEC) determined from the differential Doppler measurements of HiLat transmissions is discussed in relation to the in-situ density measurements at 830 km. The results are also utilized to illustrate the dependence of ionospheric structure parameters on short-term variability of solar activity during the sunspot minimum period. Special effort is made to illustrate that the joint study of scintillation/TEC and in-situ parameters provides an insight into the nature of magnetospheric coupling with the high latitude ionosphere.

INTRODUCTION

A wide variety of C^3I systems suffers degradation in performance due to phase and intensity scintillations imposed by the ionospheric irregularities of electron density. There is a great deal of interest in understanding the development of such irregularities at high latitudes where the ionosphere is often strongly coupled with the magnetosphere. In such an environment the distant magnetosphere serves to activate different sources of free energy, e.g., electron precipitation, field aligned currents, electric fields, etc., that control the formation of ionospheric irregularities. No longer is it possible to pursue a study of the irregularity development in the local ionospheric environment without considering the coupling between the ionosphere and the magnetosphere. This approach is particularly useful in extrapolating our knowledge of the natural ionospheric irregularity structures to problems related to the structuring of artificially injected plasma clouds in the high latitude ionosphere.

In an effort to pursue a study of plasma structuring in the above context, the Defense Nuclear Agency (DNA) launched, on 27 June 1983, the HiLat satellite in a circular 830-km orbit at 82^{o} inclination (Fremouw et al., 1985). The satellite transmits coherent signals at 137, 390, 413, and 436 MHz and the phase reference signal at 1239 MHz to measure complex signal scintillation and total electron content (TEC). It also carries a variety of in-situ probes providing measurements of ion density, ion drift, energetic electron precipitation, field aligned currents, and emissions at two visible wavelengths. All instruments except the Langmuir probe, the vacuum-ultraviolet imager and a part of the magnetometer continue to operate reliably. The major objective of the HiLat satellite program is to provide a quantitative specificiation of high latitude scintillation strength and, in particular, the temporal and spatial spectra of intensity and phase fluctuations and the shape of the irregularity structures. These parameters provided by the radio beacon experiments are supported by the simultaneous in-situ data that define the background ionospheric processes. The morphology of ionospheric structures and magnetospheric control thereof derived primarily from HiLat observations at Sondrestrom, Greenland have been enumerated by Vickrey et al. (1985).

In this paper we shall concentrate on the HiLat satellite observations performed by the Air Force Geophysics Laboratory at Tromso, Norway during the 1984-1985 period. The station is located in the central part of the auroral oval during the nighttime under magnetically quiet conditions as defined by the planetary magnetic index $Kp < 3.5$. We shall study the strength and the structure specifications of complex signal scintillations in the spatial and temporal frames of invariant latitude and magnetic local time. These distributions will then be examined in the context of in-situ plasma structures observed by the HiLat satellite in this environment and the

theoretical predictions of structures that characteristically develop in this region through gradient drift and Kelvin Helmholtz instability processes.

RESULTS

In this section we shall first illustrate the space time variations of the statistical parameters that define the complex scintillation magnitudes and their structure. In order to avoid the effects of multipath propagation, the data acquired above a satellite elevation angle of 20° were used in the study. This provided a maximum latitude coverage of about $\pm 7^{\circ}$ at an ionospheric height of 350 km around the station. Due to precession of the HiLat orbit to earlier times each day, a full coverage in local time is also obtained over a season (i.e., 3 months) when the ascending and descending node passes are combined.

The top and bottom panels of Figure 1(a) illustrate the rms phase deviation of 137 MHz scintillation for winter 1983 (start of observations in December 1983 to January 1984) and summer 1984 (May-July, 1984) respectively for Kp < 3.5. The rms phase deviation is computed over a 30-second data interval. Since the projected scan velocity of the satellite is 3 km/sec at 350 km, the data interval covers irregularity scale sizes as large as 90 km. The data are binned in 2.5° latitude and 1 hour time intervals and the median values for each bin are indicated in the diagram. Each bin contains at least ten data points. The tic marks along the noon-midnight and the dawn-dusk meridians indicate 10° intervals between 50°-90° invariant latitudes (to be denoted as Λ). The sharp increase in rms phase deviation exceeding 5 radians over a narrow latitude swath (65°-$67.5^{\circ}\Lambda$) between the pre-midnight and dawn periods is the most conspicuous feature of both diagrams. This region of enhancement corresponds to the location where the alignment of the ray path with the magnetic L-shell occurs (Rino et al., 1978). This region also coincides with the location of the diffuse aurora which is the seat of density irregularities. As we shall show later the region has enhanced total electron content (TEC) on a statistical basis due to the occurrence of plasma density blobs. Thus a combination of high irregularity amplitude, increased TEC and geometrical factors contribute to the pronounced increase of phase scintillations. Comparing the top and bottom panels of Figure 1(a) the magnitude of phase scintillations during winter is found to be larger than summer. This may appear to be somewhat intriguing because the TEC (to be shown later) was higher in summer. This leads us to conclude that the irregularities are probably less preponderant during summer in the presence of enhanced ionization of the underlying E-region.

The top and bottom panels of Figure 1(b) show the behavior of rms phase deviation at 137 MHz during February-April and August-October, 1984. The nighttime enhancement of phase deviation between 65°-$67.5^{\circ}\Lambda$ is again observed. The larger phase deviation observed during the vernal equinox can be related to increased solar activity during this period as will be shown in a subsequent diagram.

The remaining results will be presented in a different format and will indicate the variations of the statistical parameters with invariant latitude in the midnight and noon time periods only. These are basically obtained from a noon-midnight cut through the dial plots shown in Figures 1(a) and 1(b). When the number of data points in a particular bin over the noon-midnight sector fall below ten, the values are extrapolated from an adjacent time sector. Figure 2 shows such a plot for rms phase deviation obtained during 1984 and 1985. This figure illustrates an overall decrease of scintillations in 1985 due to decreased solar activity.

The intensity scintillation magnitudes have been expressed in terms of the standard S_4 index, defined as the normalized variance of signal intensity (Briggs and Parkin, 1963). Figure 3 shows the variation of S_4 index at 137 MHz with invariant latitude during noon and midnight observed during 1984 and 1985. The nighttime enhancements of S_4 index in the region of alignment of the ray path with the magnetic L-shell (65°-$67.5^{\circ}\Lambda$) is observed to be much less pronounced when it is compared to σ_{ϕ} enhancements shown in Figure 2. This indicates that the L-shell alignment of km-scale irregularities causing intensity scintillations is considerably less than the irregularities in the tens of kilometers scale that control the σ_{ϕ} values. The nighttime scintillation magnitudes during February-April, 1984 are again higher than that during August-October, 1984 due to enhanced solar activity.

In Figure 4, we show the behavior of power law spectral index, p_{ϕ}, for phase scintillations at 137 MHz during 1984 and 1985. A linear least square fit to the phase spectrum indicating the variation of the logarithm of power spectral density (psd) with the logarithm of frequency is obtained over the frequency interval of 0.2 Hz to 10 Hz. The best-fit line provides p_{ϕ} as it defines the dependence of psd on frequency f as psd $\propto f^{p_{\phi}}$. Considering the scan velocity of the ray path through the F-region, the fit range 0.2 Hz to 10 Hz corresponds to the scale size regime of about 15 km to 300 m. This regime encompasses the dominant structures that cause phase and intensity scintillations at VHF and UHF over the observing data interval. From Figure 4, it may be noted that the phase spectral index is least affected by the propagation geometry and does not show significant variations with season and solar activity in contrast to the behavior of S_4 and σ_{ϕ}. There exists, however, a tendency for p_{ϕ} to increase around $65^{\circ}\Lambda$, during the nighttime. Since this location corresponds to the average location of the diffuse aurora, the associated E-region conductivity may account for damping the short scale irregularities and causing the phase spectrum to steepen (Vickrey and Kelley, 1982). This steepening may also arise from increased psd at larger scales in the geometrical enhancement region due to better L-shell alignment of large scale irregularities as noted in connection with the increased σ_{ϕ} in comparison with S_4. The enhancements of p_{ϕ} are, however, smooth and distributed in contrast to the sharp geometrical enhancements of σ_{ϕ}. Probably, the spectral steepening arises from an interplay of both geophysical and geometrical effects.

The comb of three UHF transmissions from HiLat is used to derive the total electron content of the ionosphere up to the satellite altitude of 830 km by the differential Doppler technique (Fremouw et al., 1978). Figure 5 shows the latitude variation of median TEC values during the noon and midnight for different seasons. The next diagram, Figure 6, shows the observed variation of noontime TEC in relation to the sunspot number. The effects of the solar activity and season on TEC appear to be coupled. At high latitudes, owing to the near vertical orientation of the earth's magnetic field, the ionospheric irregularities of electron density at F-region height are usually extended in altitude. The integrated effect of the irregularities on radio wave propagation, such as scintillation, is therefore, weighted by the total electron content of the ionosphere. Thus measurements of irregularity amplitude, $\Delta N/N$ (ΔN being the rms electron density fluctuation and N the background density), and total electron content may form the basis for a modeling of scintillation magnitudes.

Among the various in-situ parameters probed by the satellite borne sensors, the in-situ ion-density measurement is an important parameter. In the F-region, due to charge neutrality, the electron and ion densities are equal. Figure 7 shows the variation of this parameter with latitude in the noon-midnight time frame as a function of season in 1984 and 1985 during magnetically quiet conditions. The ion density at 830 km is observed to follow closely the pattern of TEC variations shown earlier in Figure 5. The ion density variations are also controlled by both solar activity and season.

Although we did not illustrate the variation of scintillations and background ionospheric parameters with magnetic activity, it should be emphasized that the magnetic activity in addition to sunspot number exerts overwhelming control of scintillations at high latitudes (Basu and Aarons, 1980; Basu et al., 1985). Our HiLat observations indicate that during magnetically active conditions scintillation magnitudes are enhanced during the nighttime and the region of enhanced activity extends both in the poleward and the equatorward directions. Irrespective of the level of solar activity, scintillations are enhanced during magnetic disturbances.

DISCUSSIONS

We have shown that the most notable feature in the observed scintillation morphology at this auroral station even under magnetically quiet to moderate conditions is the enhancement of scintillations over a narrow latitude interval centered at $65^{o}\Lambda$ in the nighttime sector. This narrow band increase of scintillations coincides with the expected region of geometrical enhancement due to the alignment of the ray path with the magnetic L-shell oriented irregularities. It is interesting to note that the boundary blobs which signify plasma density enhancements also occur in this region (Rino et al., 1983). The spatial configuration of the blobs is controlled by the high latitude convection pattern which is mostly E-W in the auroral region (Heelis et al., 1982). Robinson et al. (1985) have shown with the help of simulation studies that even a primarily circular patch of ionization being convected in from the polar cap would assume a narrow in latitude and elongated in longitude shape. These blobs can also develop small scale irregularities on their trailing edges through $\vec{E}\times\vec{B}$ instability mechanisms. In general, the plasma blobs transported from distant regions get continually structured in the convection field and contribute a major source of nighttime auroral scintillations.

The other notable finding related to the scintillation structure is the steep phase spectral slopes observed in the region of geometrical enhancement. This region coincides with the central part of the diffuse aurora under magnetically quiet conditions as has been recently shown by Hardy et al., (1985) from DMSP satellite observations. Unlike the limited HiLat satellite data base of particle precipitation the DMSP satellites have provided a very large amount of data which have been organized by Hardy et al. to show the characteristic variations of particle precipitation with magnetic activity. The average energy of the particle precipitation in the diffuse auroral region is on the order of a few keV which is sufficient to produce a conducting E-region. This could reduce the lifetime of small scale irregularities ($\sim$100 m) and contribute to the observed steepening of the phase spectral indices. Basu et al. (1984) have illustrated such steepening of in-situ density spectra in regions of energetic auroral particle precipitation.

The structures present in the in-situ ion density probed by the HiLat satellite have recently been investigated (Weimer 1987). This study indicates that plasma density blobs at 830 km are concentrated over a fairly narrow latitude interval. This region when mapped down the magnetic field line corresponds approximately with the region of enhanced scintillations. These results indicate that, on a statistical basis, the blobs in addition to their E-W extent are also extended along the magnetic field lines to the topside ionosphere. The altitude profiles of the blobs have been published earlier using incoherent scatter radar measurements (Vickrey et al., 1980).

The extension of blobs to altitudes as high as 830 km indicates that magnetospheric coupling effects need to be included in the analysis of high latitude F-layer instabilities. The inclusion of ion-inertia in the $\vec{E}\times\vec{B}$ instability theories results in a reduction of growth rates and generation of irregularities with spectral isotropy (Mitchell et al., 1985). In the non-inertial domain the irregularity spectra become anisotropic in the north-south and the east-west directions. Thus, the irregularity spectral indices are expected to be different in the north-south and east-west directions in the non-inertial case and identical for the inertial case. At Tromso, in addition to making HiLat observations that provide a north-south scan through the ionosphere, we have performed scintillation observations with near-stationary polar beacon satellites which provide an east-west scan controlled by ionospheric motion. The spectral indices of both sets of measurements are found to be

approximately equal indicating that the inertial effects are important in the generation of kilometer scale irregularities at high latitudes which cause VHF scintillations.

Another type of auroral irregularity not associated with large scale organized density gradients (such as to be found on the edges of blobs) but associated with velocity shears with shear gradient scale lengths ~10 km has been identified from HiLat observations (Basu et al., 1986). These irregularities, having considerable psd at the shorter scales, can cause intense VHF scintillations at the edges of auroral arcs in association with upward field aligned currents. In view of the well-known temporal and spatial variability of auroral arcs, the signature of such velocity shears will be difficult to identify in a statistical study of auroral scintillations.

REFERENCES

Basu, Su. and J. Aarons, The morphology of high-latitude VHF scintillation near 70°W, Radio Sci., 15, 59, 1980.

Basu, Su., S. Basu, E. MacKenzie, W.R. Coley, W.B. Hanson, and C.S. Lin, F-region electron density irregularity spectra near auroral acceleration and sheer regions, J. Geophys. Res., 89, 5554, 1984.

Basu, Su., S. Basu, E. MacKenzie, and H.E. Whitney, Morphology of phase and intensity scintillations in the auroral oval and polar cap, Radio. Sci., 20, 347, 1985.

Basu, Su., S. Basu, C. Senior, D. Weimer, E. Nielsen, and P.F. Fougere, Velocity shears and sub-km scale irregularities in the nighttime auroral F-region, Geophys. Res. Lett., 13, 101, 1986.

Briggs, B.H. and I.A. Parkin, On the variation of radio star and satellite scintillation with zenith angle, J. Atmos. Terr. Phys., 25, 339, 1963.

Fremouw, E.J., R.L. Leadabrand, R.C. Livingston, M.D. Cousins, C.L. Rino, B.C. Fair, and R.A. Long, Early results from the DNA Wideband satellite experiment: Complex-signal scintillation, Radio Sci., 13, 167, 1978.

Fremouw, E.J., H.C. Carlson, T.A. Potemra, P.F. Bythrow, C.L. Rino, J.F. Vickrey, R.C. Livingston, R.E. Huffman, C.-I. Meng, D.A. Hardy, F.J. Rich, R.A. Heelis, W.B. Hanson, and L.A. Wittwer, The HiLat mission, Radio Sci., 20, 416, 1985.

Hardy, D.A., M.S. Gussenhoven, and E. Holeman, A statistical model of auroral electron precipitation, J. Geophys. Res., 90, 4229, 1985.

Heelis, R.A., J.K. Lowell, and R.W. Spiro, A model of the high-latitude ionospheric convection pattern, J. Geophys. Res., 87, 6339, 1982.

Mitchell, H.G., Jr., J.A. Fedder, M.J. Keskinen, and S.T. Zalesak, A simulation of high latitude F-layer instabilities in the presence of magnetosphere-ionosphere coupling, Geophys. Res. Lett., 12, 283, 1985.

Rino, C.L., R.C. Livingston, and S.J. Matthews, Evidence for sheet-like auroral ionospheric irregularities, Geophys. Res. Lett., 5, 1039, 1978.

Rino, C.L., R.C. Livingston, R.T. Tsunoda, R.M. Robinson, J.F. Vickrey, C. Senior, M.D. Cousins, J. Owen, and J.A. Klobuchar, Recent studies of the structure and morphology of auroral zone F-region irregularities, Radio Sci., 18, 1167, 1983.

Robinson, R.M., R.T. Tsunoda, J.F. Vickrey, and L. Guerin, Source of F-region ionization enhancements in the nighttime auroral zone, J. Geophys. Res., 90, 7533, 1985.

Vickrey, J.F. and M.C. Kelley, The effects of a conducting E-layer on classical F-region cross-field plasma diffusion, J.Geophys. Res., 87, 4461, 1982.

Vickrey, J.F., C.L. Rino, and T.A. Potemra, Chatanika/TRIAD observations of unstable ionization enhancements in the auroral F-region, Geophys. Res. Lett., 7, 789, 1980.

Vickrey, J.F., R.C. Livingston, R.T. Tsunoda, C.L. Rino, N.B. Walker, T.M. Dabbs, R.M. Robinson, and R.A. Heelis, The SRI ionospheric plasma structure and dynamics program - 1985 results, Final Technical Report, SRI International, June 1985.

Weimer, D.R., Large-scale plasma density fluctuations measured with the HiLat satellite at 830 km altitude, AFGL Technical Rpt., Hanscom AFB, MA, 1987.

ACKNOWLEDGMENT

This work was supported by AFGL Contract F19628-86-K-0038 with Emmanuel College and by the Defense Nuclear Agency. The authors thank L. Wittwer, H.C. Carlson, and F.J. Rich for their interest and support.

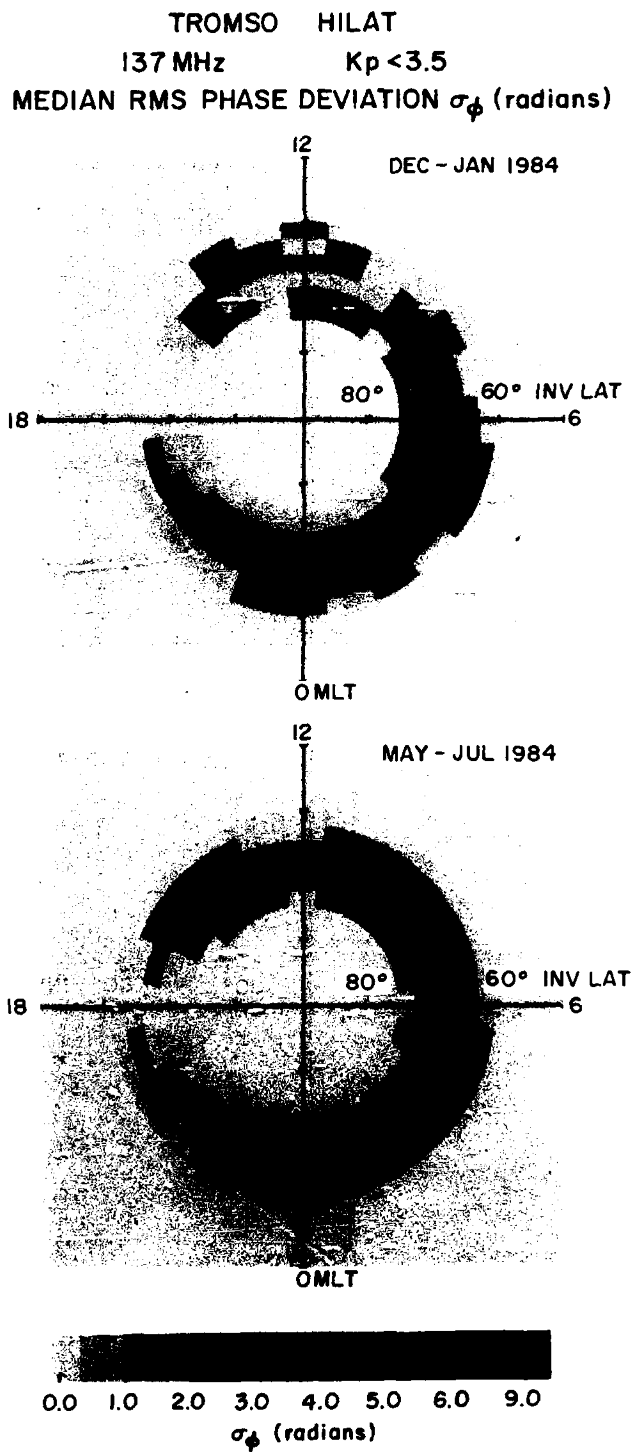

Figure 1a. Variations of rms phase deviation at 137 MHz with invariant latitude and magnetic local time during winter and summer.

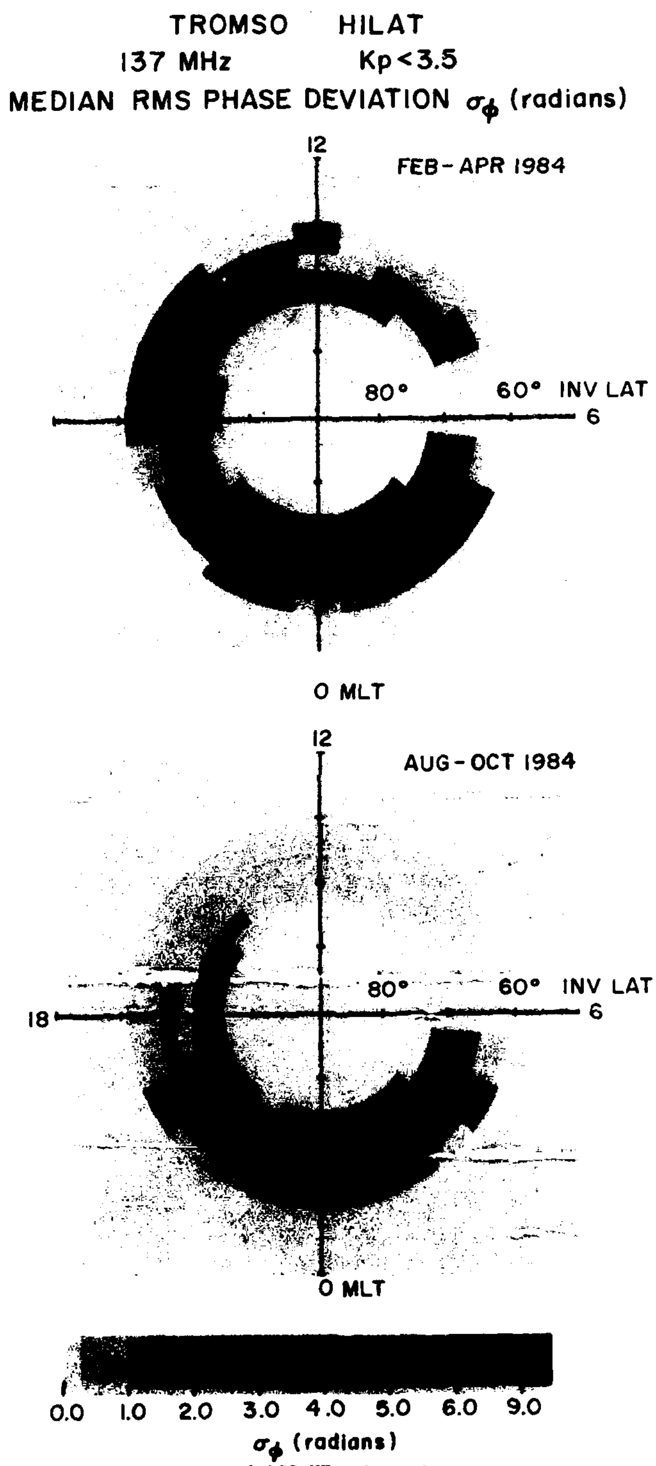

Figure 1b. Equinoctial variations of 137 MHz phase deviation with invariant latitude and magnetic local time.

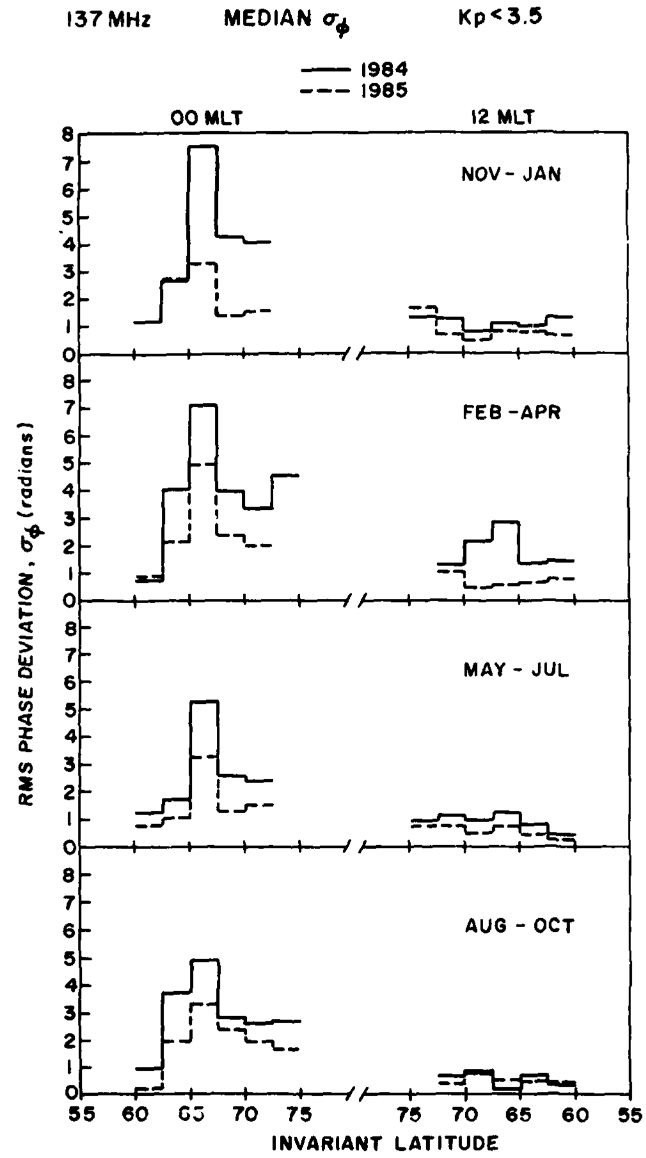

Figure 2. Seasonal variations of rms phase deviation at 137 MHz with invariant latitude along the noon-midnight meridian in 1984 and 1985.

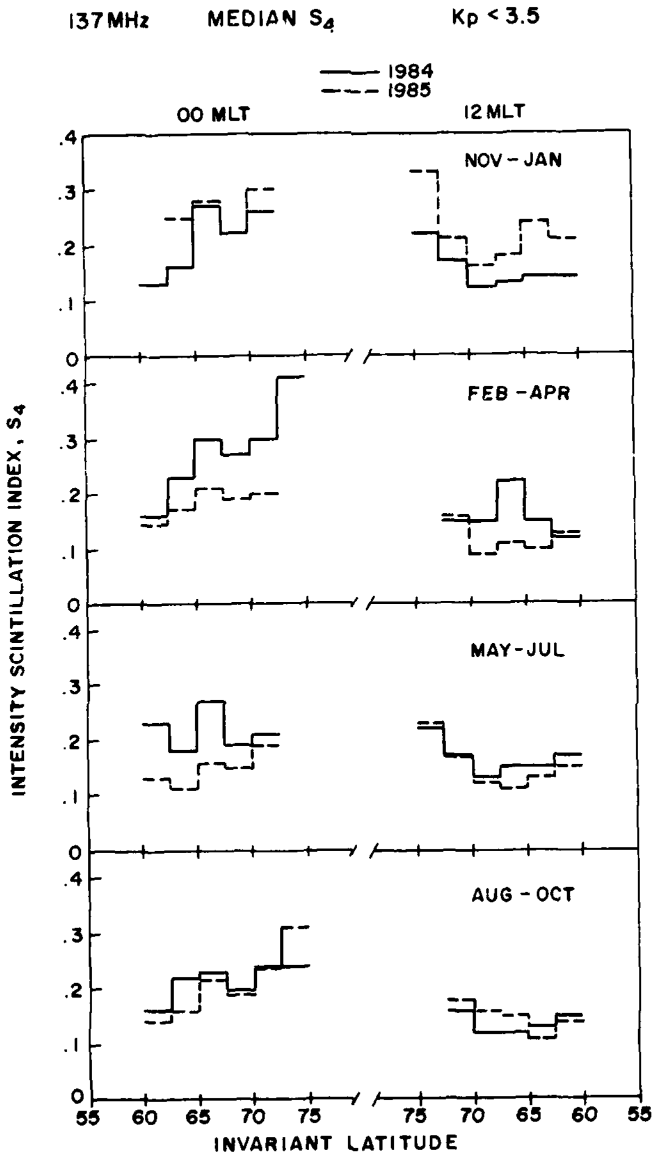

Figure 3. Seasonal variations of intensity scintillation index at 137 MHz along the noon-midnight meridian in 1984 and 1985.

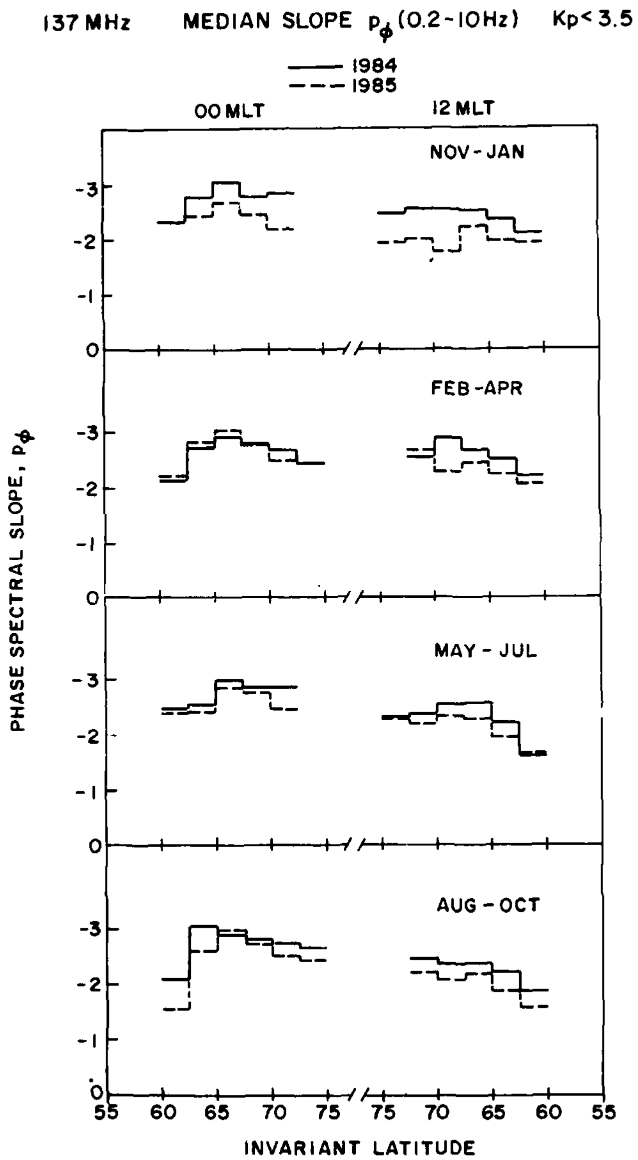

Figure 4. Seasonal variations of the slope of 137 MHz phase scintillation spectra along the interval of 0.2-10 Hz along the noon-midnight meridian in 1984 and 1985.

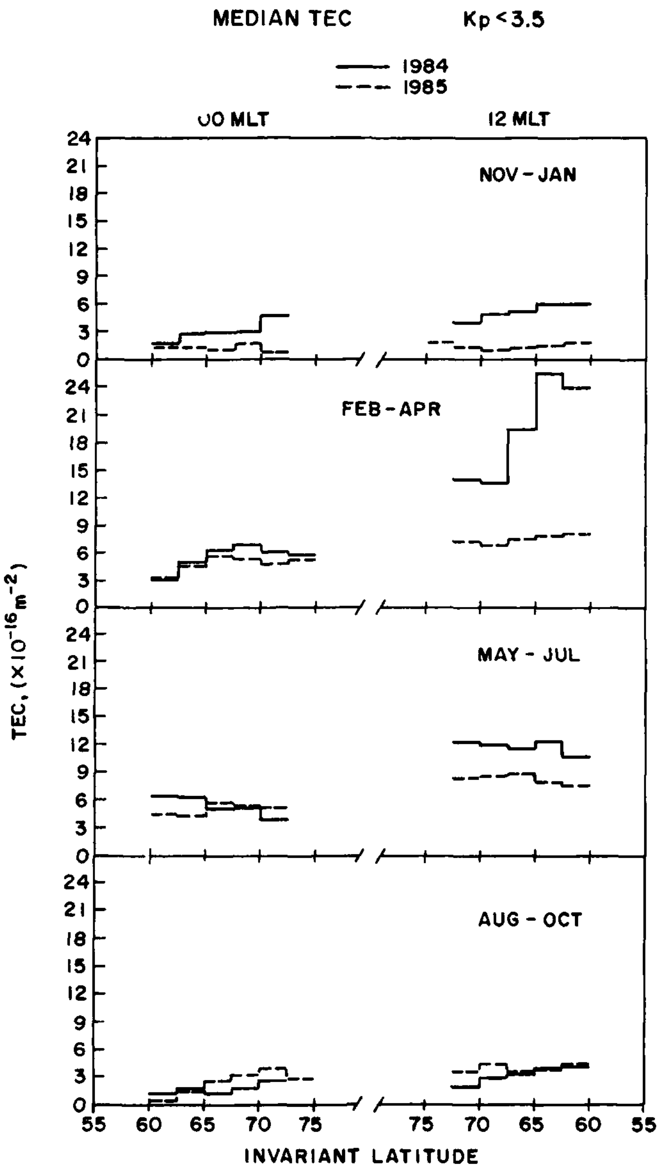

Figure 5. Seasonal variations of total electron content variations along the noon-midnight meridian in 1984 and 1985.

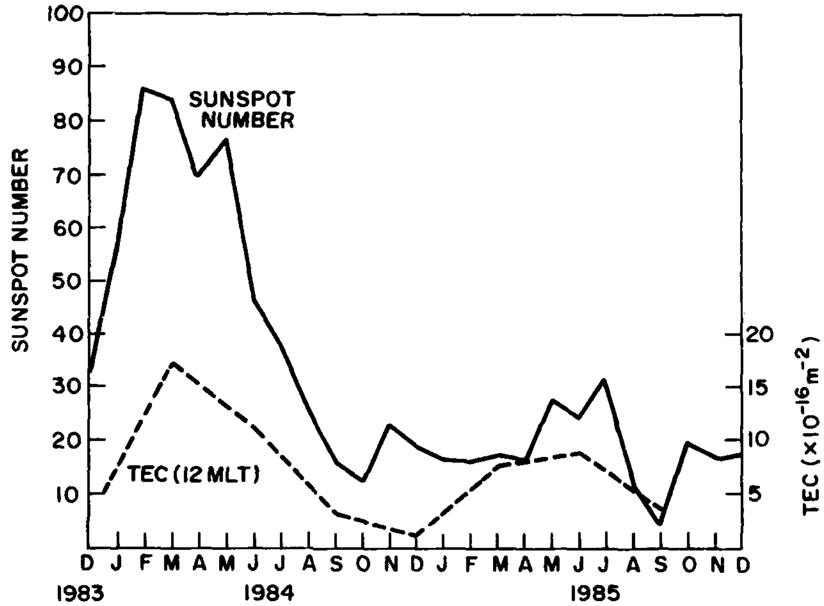

Figure 6. Illustrates the correspondence between the variations of total electron content and sunspot number.

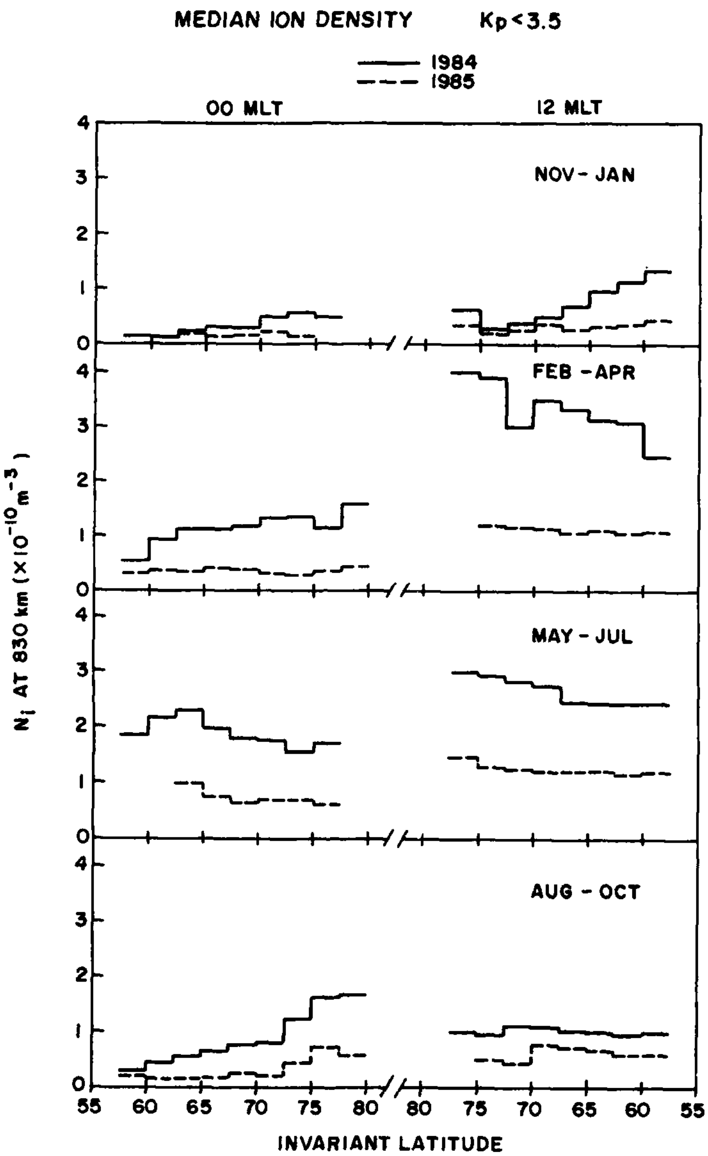

Figure 7. Seasonal variations of ion density at the satellite altitude of 830 km along the noon-midnight meridian in 1984 and 1985.